Predictive Organic Carbon Model for Andisols in the Pacific Northwest

ABSTRACT

Equations were developed to predict organic carbon (wt %) at specific depths between 25 and 100 cm and the mass of organic carbon (kg per square meter) from the surface to those depths. Data commonly available to field personnel were used as inputs to the equations. The data set used to develop the equations consisted of 75 Andisol pedons from the U.S. Pacific Northwest. Mean annual precipitation was the most important factor, with slope having a minor effect. Mean annual temperature and elevation were significant in a few cases, but aspect and latitude were not significant in most relationships. Simple transformation of the independent variables resulted in limited improvement of predictive ability at the cost of increased equation complexity. The equations predict the percent organic carbon better at the shallow depths (near 25 cm) while the organic carbon mass is predicted better at depths near 100 cm.

INTRODUCTION

Soil organic matter is central to the cycling of plant nutrients, influences water relations and erosion potential, and is a key factor in soil structure (Tisdale and Oades, 1982; Parton et al., 1987). Efficient models are needed for predicting soil properties such as organic matter in order to populate the USDA, Natural Resources Conservation Service (NRCS), National Soil Information System (NASIS) database. This database provides soils information for interpretation, classification, and research. In this paper, we develop a model to predict organic carbon in Andisols and closely associated soils in an area of the Pacific Northwest.

Carbon distribution in soils shows considerable variability, i.e., geographically, as a function of depth, and spatially as a function of position on the landscape. This variability complicates the task of making reliable estimates of soil C (Eswaran et al., 1995). Pedon data represent the most comprehensive and detailed available set of laboratory measurements, including bulk density, and descriptive properties of soils as they occur with depth and across the landscape, and at the same time, provide information for predicting soil properties at other locations (Levine et al., 2000).

Estimates of organic carbon in soils have been made on a global scale (Eswaran et al., 1993; Kimble et al., 1990; Post et al., 1982; Bohn, 1976, 1982; Sanchez, 1982). Every study shows considerable variability (r^2), due in part to the use of broad-scale groupings, e.g., soil orders (U.S. Soil Taxonomy, 1975, 1999), soil associations (FAO-UNESCO, 1971-1981 Soil Map of the World), and life zones (Holdridge, 1947).

Estimates of organic carbon in soils have also been made on a regional scale. Unpublished soil reports by the USDA-NRCS Lincoln Laboratory for projects in the mountains of the Western U.S. have shown that elevation, slope, aspect, precipitation, and soil temperature are good predictors of the carbon content of the soils. These reports also suggest the efficiency of the model decreases as the extent of the geographic area increases.

In most soils, there is an exponential decrease of carbon with depth, with the highest concentration in the surface horizon (Eswaran et al., 1995). In Andisols, approximately 55 percent of the organic carbon is stored in the upper top 25 cm while the top 50 cm holds approximately 88 percent (Eswaran et al., 1995).

The objective of this study was to develop predictive equations for organic carbon in Andisols in the Pacific Northwest, using information that would typically be available to field soil scientists [elevation (m), mean annual soil temperature (°C), mean annual precipitation (mm), aspect (degrees), slope (degrees), and latitude (degrees)]. Scientists following the global carbon cycle need estimates of each map unit. Since organic carbon content in Andisols highly correlates with other chemical and physical properties, organic carbon content may provide more accurate predictions of these properties.

MATERIALS / METHODS

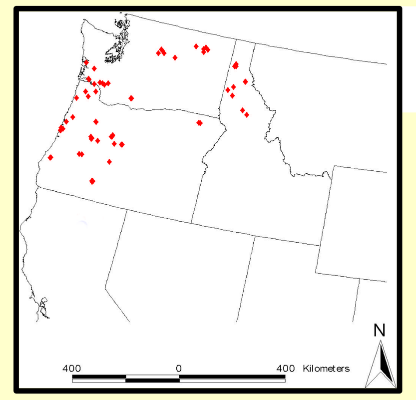

Figure 1. Pedon locations.

Data from 75 Andisol pedons from Washington, Oregon, and Idaho (representing 49 series) for which the NRCS has characterization data were used to develop predictive equations for the percentage of organic carbon (OC) (wt %) at 25, 30, 60, 70, and 100 cm depths. Equations were also developed to predict the total mass of OC (kg/m^2) from the surface of the mineral soil to those depths. Pedon locations are shown in Fig. 1.

Only pedons with organic carbon contents that decrease regularly with depth were included. The Pelee pedon (S81WA059005, Fig. 2) is an example of those that were excluded. Pedons with slight irregularities in OC distribution that were assumed to be within the analytical and sampling error were included. Fig. 3 is an example of such an OC distribution. Soils with histic epipedons were also excluded. The Lapine pedon (Fig. 4a and 4b) is an example of one of the Andisols with low organic carbon content. The Germany pedon (Fig. 5a and 5b) is an example of one of the pedons with high organic carbon content.

Since the OC values in the National Soil Survey Laboratory (NSSL) database are an average for the entire thickness of a horizon, a computer program was developed to refine these values to provide more reasonable estimates of the OC at specific depths. The procedure is:

1) Locate the midpoint of each horizon.
2) Consider a vertical line segment from the top to the bottom of the horizon, located horizontally at the position of the measured OC value.
3) Allow this line segment to rotate about the horizon midpoint. This satisfies the condition that the average OC content of the horizon is the measured amount, but allows an estimated OC distribution that is not a step function at horizon boundaries.
4) Locate the horizons with the local maximum and minimum of the OC distribution in the pedon.
5) Start with the lowest minimum. If local, leave the line segment vertical, and work in both directions, rotating the adjoining line segments to touch at the boundary, if possible. If it is not possible to force the segments to touch, minimize their offset at the horizon boundaries.
6) If a local maximum is encountered, leave that line segment vertical, and rotate the adjoining line segments to touch the maximum segment, or minimize the offset.
7) After all line segments have been rotated to a preliminary fit, locate the largest offset or greatest slope change between line segments at a horizon boundary. Rotate the non-vertical line segment(s) at the boundary to reduce the offset or slope change by a small amount (3 to 5%), and recalculate the rotation of the other line segments (working outward) to match the new rotations.
8) Evaluate the new segment rotations. If the new maximum offset or slope change is greater, or if an offset exists where lines previously joined, discard the adjustments and retain the previous rotation information.
9) Repeat steps 7 and 8 until no additional improvement is noted.
10) Calculate the estimated OC at the depths of interest, using the slope of the applicable line segment and the difference in depth from the horizon midpoint.
11) Calculate the summed OC to the depths of interest by adding the OC for all overlying horizons, then calculate the area to the left of the line segment down to the depth of interest in the last horizon, and add it to the preceding total.

Fig. 6 shows the OC distribution of an Astoria pedon (S64WA027003) as a series of bars representing the measured values and horizon thickness. Fig. 7 shows the best fit rotated line segments for the same pedon. The red dot on the line indicates the 60-cm depth, and the blue shaded area is the zone over which OC was summed to obtain the estimated amount to that depth.


Figure 2. A soil with irregular OC distribution – not included in this study (Pelee series, S81WA059005).

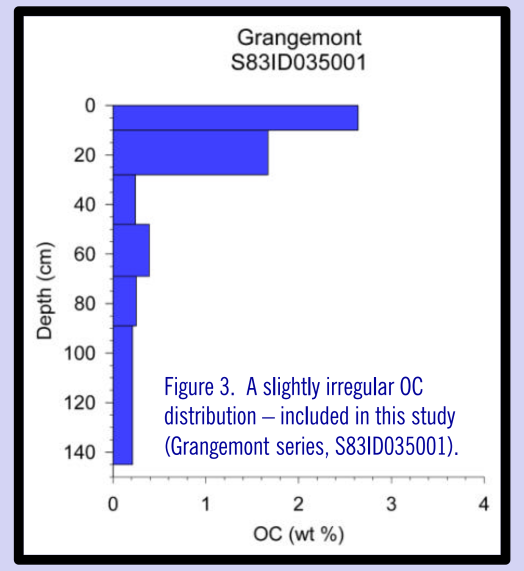

Figure 3. A slightly irregular OC distribution – included in this study (Grangemont series, S83ID035001).

Figure 4a. A pedon with low amounts of OC (Lapine series, S72OR027010).

Figure 4b. The setting of the Lapine series (S72OR027010).

Figure 5a. A pedon with relatively high OC (Germany series, S84WA069004).

Figure 5b. The setting of the Germany series (S84WA069004).

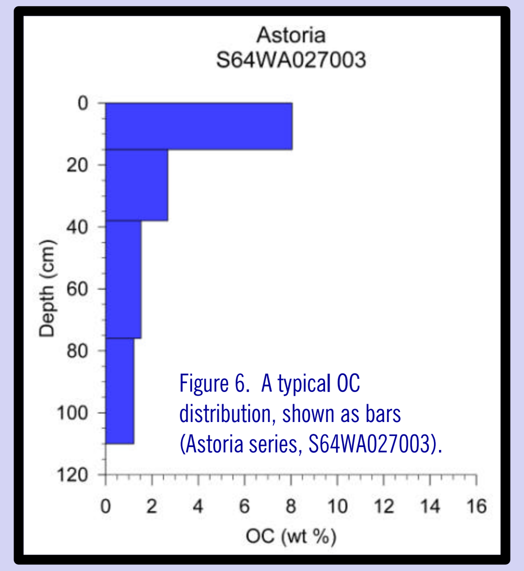

Figure 6. A typical OC distribution, shown as bars (Astoria series, S64WA027003).

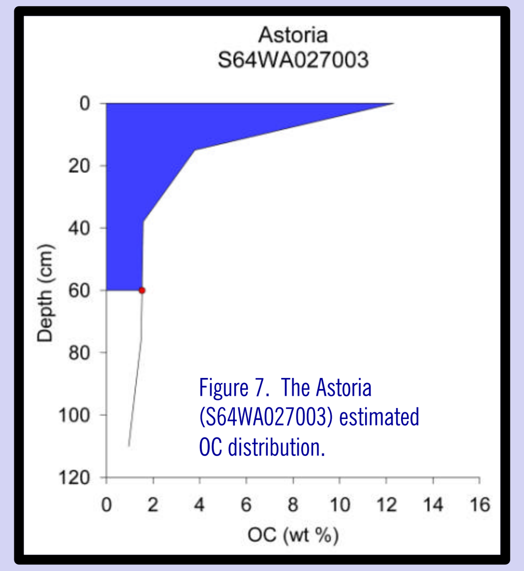

Figure 7. The Astoria (S64WA027003) estimated OC distribution.

RESULTS & DISCUSSION

Correlation

The pedons in this data set are from a fairly broad geographic area. The more general independent variables show the most consistent relationships with the estimated OC values.

Mean annual precipitation (MAP) has the highest correlation with the OC values. The correlation is positive, ranging from 0.82 to 0.83 for the summed to depth OC values, and from 0.79 to 0.65 for the estimated OC values at specific depths. The correlation was higher at the shallower depths, in the latter case.

Mean annual soil temperature (MAST) correlations with the summed to depth OC values ranged from 0.54 to 0.63 (increasing with depth). MAST correlations with the OC estimates at specific depths ranged from 0.48 to 0.36 (decreasing with increasing depth).

The correlation between elevation and the summed to depth OC values ranged from -0.57 to -0.73 (becoming more negative with increasing depth). Elevation correlations with the estimated OC at specific depths ranged from -0.59 to -0.49 (becoming less negative with increasing depth).

Slope had correlations with the summed to depth OC values ranging from 0.03 to 0.20. The 0.03 correlation was for the 100 cm depth – the other correlations were approximately 0.20. Correlations between slope and the estimated OC at specific depths ranged from 0.05 to 0.33, with all values except that for 100 cm being in the 0.25 to 0.33 range.

Two different methods were used to place aspect degrees into classes. Neither resulted in significant correlations with the summed to depth OC values or the estimated OC at specific depths. Correlations were typically in the -0.10 to 0.10 range. Possibly no correlation with aspect in this data set is due to the influence of aspect being overshadowed by larger differences due to MAP, MAST, slope, and elevation.

The latitude value was missing for several of the pedons. Inclusion of latitude in regression model statements resulted in a small 'n' value (usually approximately 20), so latitude was not included in the final regression procedure models. For those pedons having latitude values, correlations ranged from -0.36 to -0.17 (becoming less negative with increasing depth) for the summed to depth OC values. Correlations with the estimated OC at specific depths ranged from -0.25 to -0.02.

Transformation

Three of the independent variables were transformed in an attempt to linearize their relationship with the OC values. MAP values were squared, and slope and latitude were cubed. Transformed MAP values did not correlate significantly better with the summed to depth OC values. Transformed MAP values correlated slightly better (approximately 0.04 improvement) with the estimated OC at specific depth values.

Transformed slope values correlated better with the summed to depth OC values. The improvement ranged from 0.03 to 0.14, increasing with increasing depth. The improvement in correlation between the transformed slope values and the estimated OC at specific depth values ranged from 0.05 to 0.17, increasing with increasing depth.

No improvement in correlation with OC values was observed for the transformed latitude values.

Geographic Subsetting

The original data set (n = 82) contained pedons from California, Washington, Oregon, and Idaho. As a part of the analysis, the pedons from Idaho and California were removed (one state at a time, and both states together) to see if the predictive equations improved. Removing both states' pedons did improve the equations (particularly for those OC values that were predicted least effectively in the entire data set). Removing just the Idaho pedons did little to improve the equations, indicating the relationships in the Idaho pedons were similar to those in the Washington and Oregon pedons. Removing the California pedons resulted in a noticeable improvement in several equations, indicating the relationships between the dependent and independent variables are substantially different from those in the rest of the data set. The data set without the California pedons (n = 75) was used for subsequent analyses.

Predictive Equations

SOC followed by a number represents the OC mass (kg/m^2) summed from the mineral soil surface to that depth in cm. OC followed by a number represents the estimated OC (wt %) at that depth in cm.

$OC25 = 0.319 + 0.000086MAP^2 + 0.000009Slope^3$, $r^2 = .68$, $n = 51$

$OC30 = 0.155 + 0.000081MAP^2 + 0.000007Slope^3$, $r^2 = .60$, $n = 51$

$OC60 = -0.014 + 0.000037MAP^2 + 0.000003Slope^3$, $r^2 = .66$, $n = 51$

$OC70 = 0.053 + 0.000024MAP^2 + 0.000003Slope^3$, $r^2 = .70$, $n = 51$

$OC100 = 0.092 + 0.000011MAP^2 + 0.000001Slope^3$, $r^2 = .55$, $n = 51$

$SOC25 = -1.599 + 0.441MAST + 0.044MAP$, $r^2 = .67$, $n = 53$

$SOC30 = -2.124 + 0.485MAST + 0.052MAP$, $r^2 = .71$, $n = 53$

$SOC60 = 5.571 - 0.005Elev + 0.080MAP$, $r^2 = .73$, $n = 54$

$SOC70 = 5.996 - 0.005Elev + 0.085MAP$, $r^2 = .74$, $n = 54$

$SOC100 = 6.984 - 0.006Elev + 0.095MAP$, $r^2 = .75$, $n = 54$

MAP^2 and slope^3 are the two most significant variables to predict OC values at specific depths.

MAP and MAST are the two most significant independent variables to predict the OC values summed to the 25-cm and 30-cm depths. MAP and elevation are the most significant variables predicting OC summed to greater depths.

CONCLUSIONS

In the absence of laboratory measurements, slope and MAP together account for 68 percent of the variability in the organic carbon content of Andisols of the Pacific Northwest at the 25-cm depth.

Elevation and MAP account for 75 percent of the variability in the mass of organic carbon at a depth of 1 m. The mass of organic carbon to shallower depths is almost as predictable.

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